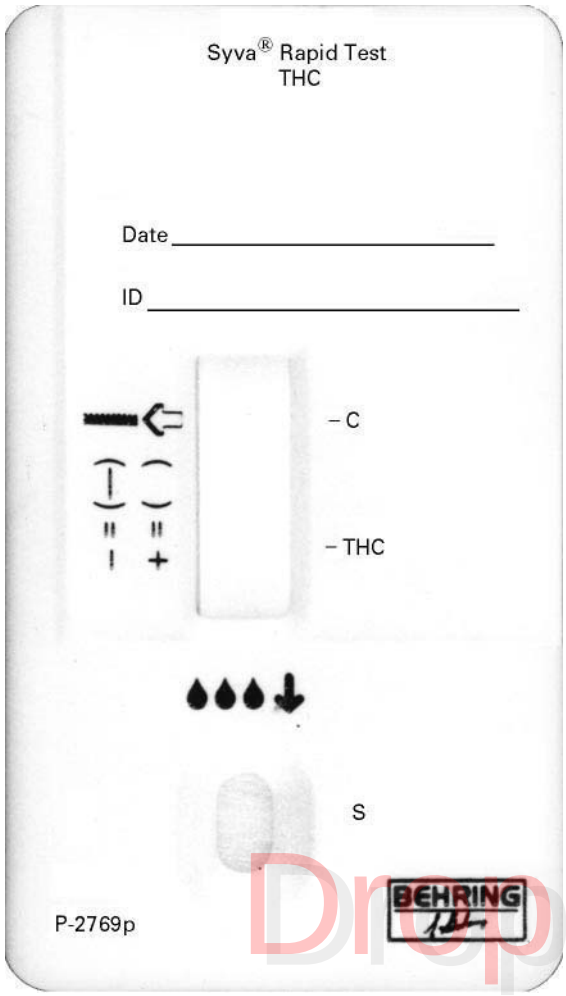

Figure 6 Immunochromatography slide for once-only use near the subject testing to detect abused drugs. C = control, THC = tetrahydrocannabinol, a metabolite of cannabis.

'sticks' which use immunochromatography. The principle is that the sample, e.g. urine, is applied to the stick which is then developed, e.g. by capillary attraction, the analyte of interest binding at a zone where there are antibodies. There are sometimes built-in positive and negative controls. When the antigen and antibody combine they develop a visible colour spot or band which confirms the presence of the compound of interest (**Figure 6**). While these devices are expensive and inaccurate they have the benefit of immediacy which may be clinically acceptable provided they are used appropriately.

The Future

Chromatography has maintained its role in certain niches in clinical laboratories. Interest in manufacturer-supplied solutions for chromatography, particularly LC, exists and compensates for the lack of skill base. For difficult low throughput analyses this may be how developments will be consolidated. Capillary zone electrophoresis could impact on much current LC work but again skill and capital costs militate against this. If accuracy rather than imprecision becomes a major clinical laboratory issue, as it may, then the inherent accuracy of chromatography probably linked to mass spectrometry will provide a role for definitive methods and may provide a role for methods used in routine laboratories.

See also: **II/Chromatography: Thin-Layer (Planar): Mass Spectrometry. III/Toxicological Analysis: Liquid Chromatography.**

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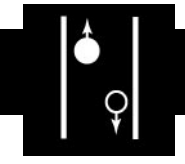
COAL: FLOTATION



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Introduction

The process of froth flotation for upgrading the quality of coal by removing mineral matter (ash and pyrite) has received increased attention since the 1960s. The froth flotation process is typically used for treating <0.5-mm size coal and is currently the only technique both effective and economical to clean coal on a commercial scale. In the USA, the majority of coal preparation plants discard the <0.5-mm coal owing to the high cost of processing of the fine coal.

Recovering fine coal offers important economic and environmental functions. In economy terms, the plant recovers an extra amount of clean coal that would have otherwise been discarded to the impoundment. Recovering the clean coal reduces the amount of fines to the ponds, and improves the quality of recycled water.

The basic coal flotation technology has been derived from ore flotation, where the technology has been extensively used. The first froth flotation plant for coal was established in the United Kingdom in 1920 and the first US plant was established in 1930. Froth flotation technology has made substantial progress over the last fifty years.

Coal is a solid combustible material and exists in the ground along with impurities. Coal, being composed of carbon elements, is hydrophobic in nature and thus is a good candidate for the froth flotation technique. The impurities present in coal basically consist of clays, quartz, calcite, dolomite, pyrite, chlorite, etc. which are hydrophilic in nature and thus, can be eaily removed in an aqueous medium. Pyrite minerals present in coal have an ambivalent character and are sometimes difficult to remove by the flotation technique.

Hydrophobicity of Coal

The hydrophobicity of coal varies with the rank of the coal and oxygen functional group present in the coal. The high volatile bituminous coals are the most hydrophobic, whereas lignite is the least hydrophobic. One technique to quantify the hydrophobicity of coal is through measuring contact angles of water on coal surfaces. **Figure 1** shows the contact angle data of water on various coals. Note that the maximum contact angle or the hydrophobicity occurs at $\sim 88\%$ C, and the high-carbon content anthracite coals are less hydrophobic.

Zeta Potential of Coal

The zeta potential of various coals with respect to pH is shown in **Figure 2**. Note that the point of zero charge (PZC) is highly variable and depends on the source and type of coal. The sub-bituminous and lignite have a PZC of ~ 2, whereas the high volatile (hvA) bituminous and anthracite coals have a PZC of ~ 5. In general, a reduction in the PZC value indicates a reduction in hydrophobicity.

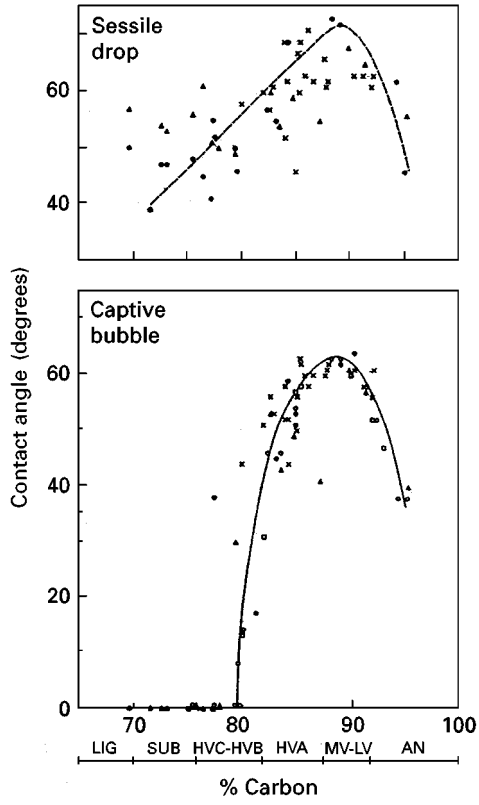

Figure 1 Hydrophobicity of various coals as a function of percentage carbon based on the contact angle technique. (Aplan (1989), courtesy of SME, Littleton, Colorado, USA.)

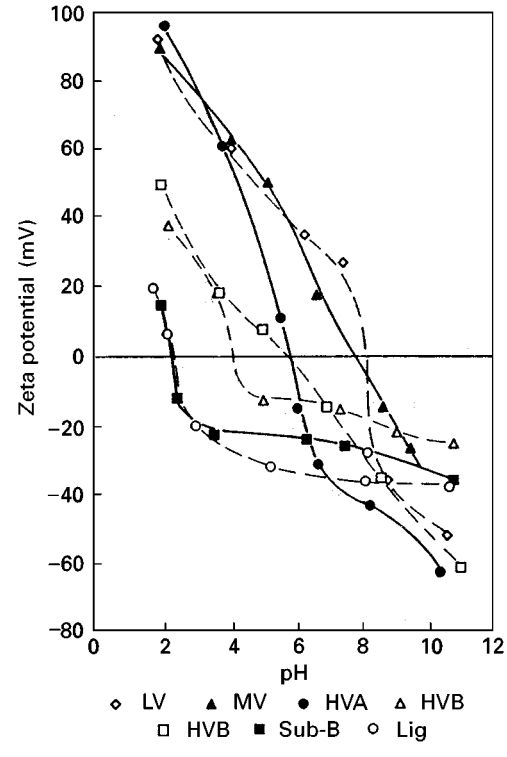

Figure 2 Zeta potential and point-of-zero charge (PZC) of coals of various ranks. (Aplan and Arnold (1991), courtesy of SME, Littleton, Colorado, USA.)

Reagents

The purpose of flotation reagents is to provide a strong hydrophobic surface and to create small relatively stable bubbles. For coal flotation, in general, only the collector and frother reagents are used.

Collectors

Theoretically speaking, the highly hydrophobic coals (containing 85–90%C) should not require any collector. In practice, a small amount of either No. 2 fuel oil or kerosene is used as collector. The amount of a collector required varies from a low (0.11–0.2 kg t^{-1}) for a high rank coal to a high (1.0–2.0 kg t^{-1}) for a low rank coal.

Frothers

The primary function of the frother is to produce a large quantity of fine size bubbles. The bubbles should be able to carry the coal to the surface without breaking, and once out of the flotation machine, it should break down. The most commonly used frothers for coal flotation are either pure alcohol, e.g. MIBC (methyl isobutyl carbinol) or a mixture of various alcohols and the polypropylene glycol-based frothers. The amount of frother required varies from 0.2 to 0.5 kg t^{-1}.

Depressant

The function of depressant is to suppress the flotation of one component of the mixture of solids by adding a specific chemical. In coal flotation, pyrite usually floats along with the coal. Many papers have been published on the subject; however, Chaudhari and Aplan, and Xu and Aplan, have conducted a detailed investigation of various reagents for depressing flotation of pyrite. They concluded that there is no universal reagent for depressing pyrite. In the coal industry, pyrite depression is not practised; however, in the future this might become an important step for the coal industry to survive.

There are some other variables for flotation, such as pH, dispersing reagents, percentage solids, particle size, etc. However, in the coal industry, very little or no attention is given to these factors. Readers interested should refer to Aplan's work.

Flotation Machines

The coal industry uses either mechanical or column cells.

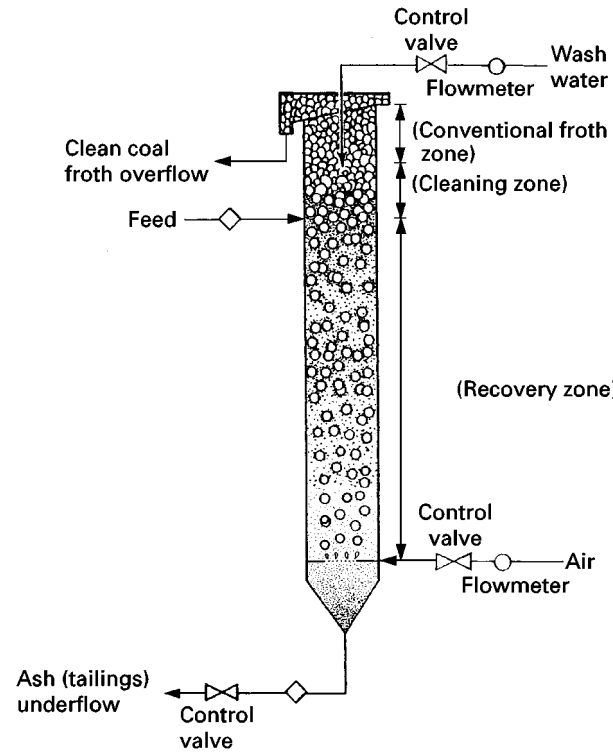

Figure 3 A line diagram of a column flotation cell.

Mechanical

The most commonly used flotation machine is one in which a mechanically driven impeller agitates in the pulp and disperses air into it. The major development in mechanical flotation cells has been in the design of

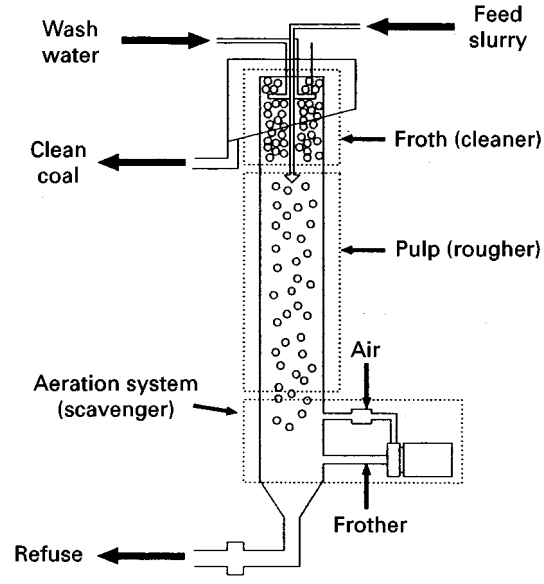

Figure 4 Schematic diagram of the Microcell™. (Yoon *et al.* (1992), courtesy of Gordon and Breach Science Publishers.)

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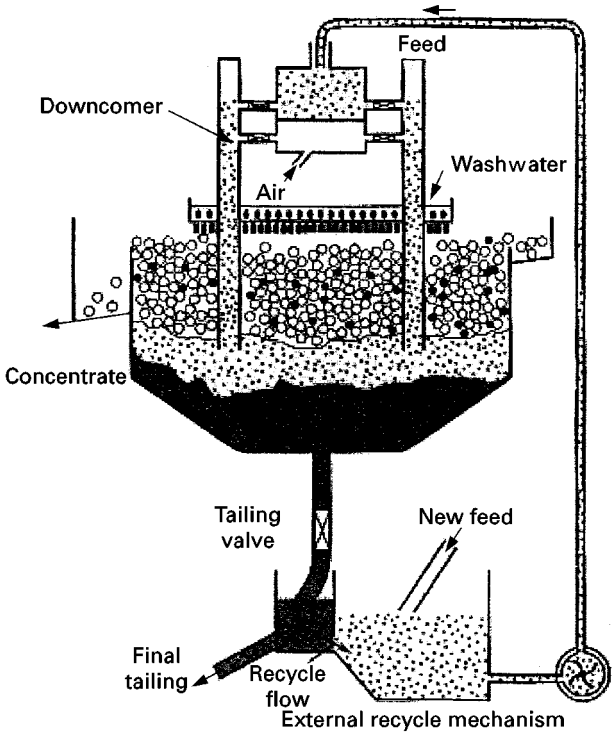

Figure 5 Schematic of Jameson cell. (Courtesy of Richwood Industry, Huntington, West Virginia, USA.)

larger volume machines (3000 ft^3 or 84 m^3). For coal flotation, mechanical cells are usually arranged in banks of four to six cells in an 'open-flow' arrangement.

Column

The column flotation cell which has achieved success in the mineral industry was introduced to the coal industry in the 1990s. The machine consists of a long (~6 m) vertical tube ranging from 2.4 to 3.0 m in diameter. **Figure 3** shows a sketch of the column flotation machine. The feed (coal slurry containing flotation reagents) to the column is introduced at about the 5-m level. The froth height is maintained close to 1 m and wash water introduced into the froth layer to remove any entrapped and entrained impurities. The tailings containing the impurities (ash) are discharged at the bottom of the column. A variety of column flotation machines have been developed over the last few decades. The Ken-Flote column developed at the University of Kentucky Center for Applied Energy uses either a porous cylinder or a 'foam-jet' system to generate bubbles and provides a quiescent zone for attachment of coal particles to the air bubbles, which keeps ash entrainment to a minimum. In 1989, the first commercial Ken-Flote

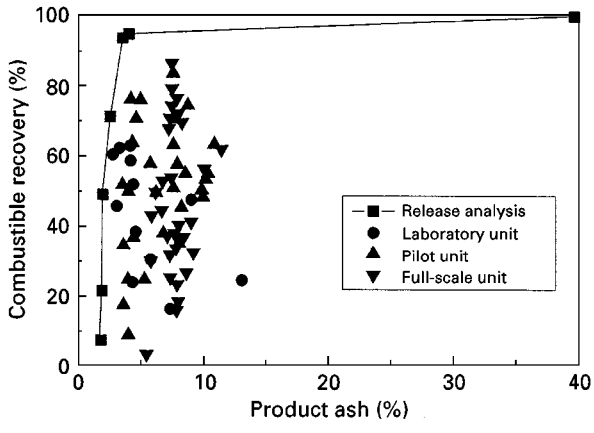

Figure 6 Performance data of the Jameson cell at the laboratory, pilot, and full scale. (Honaker *et al.* (1999), courtesy of SME, Littleton, Colorado, USA.)

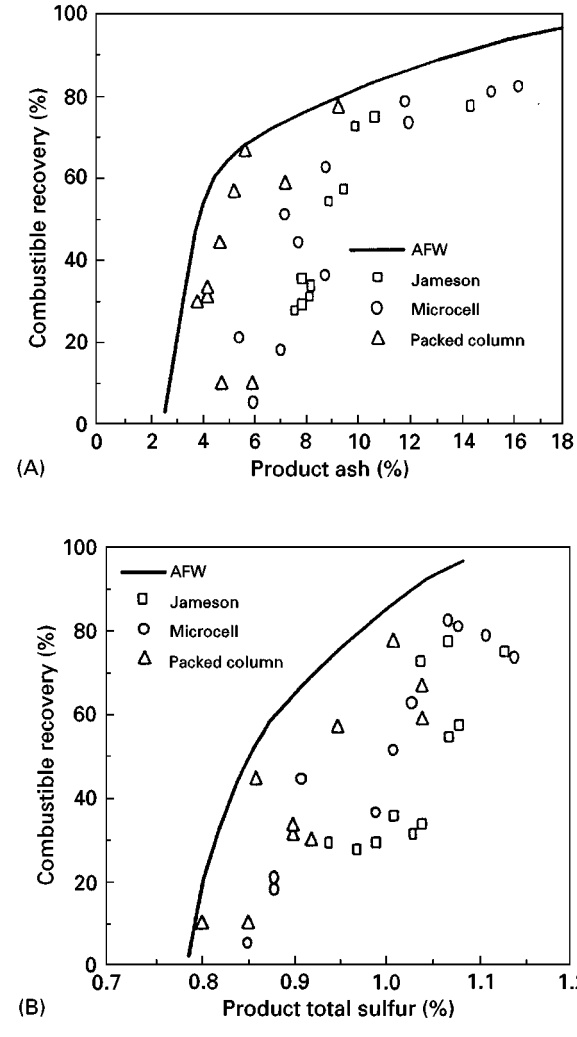

Figure 7 Metallurgical performance achieved by the three column flotation technologies and the advanced flotation washability (AFW) analysis on the basis of (A) product ash and (B) total sulfur contents (feed ash: 42.6%; total sulfur: 0.86%). (Mohanty and Honaker (1999), courtesy of Elsevier Science.)

columns were installed in the USA at the Powell Mountain Coal Company, Virginia.

The 'Mocrocel' column flotation developed at the Virginia Polytechnique and State University uses an inline mixture to generate fine bubbles in the column. In this column, a part of the reject stream is passed through the inline mixture along with the frother and air to generate fine bubbles. **Figure 4** shows a diagram of the Microcell™ column.

The Static Tube flotation system developed at the Michigan Technology University uses corrugated plates packed inside the column to break up large bubbles into a smaller size bubble. The machine does not utilize any special bubble-generating device.

The Jamison cell is a column cell that is much shorter than any of the columns described earlier. As shown in **Figure 5**, the Jamison cell utilizes a pressurized feed stream injected through a long tube called the downcomer to draw atmospheric air into the device. The resulting jet formed is discharged into a short column where coal floats to the surface and tailings are discharged at the bottom. Wash water is generally added through a tray located above the froth phase. Currently, quite a few Jamison cells are being used in Australia and a few coal preparation plants in the USA. **Figure 6** compares the separation performance as a function of ash content for a coal using the laboratory-, pilot- and full-scale Jamison cell units. The L-shape of the release curve indicates that the impurities in the coal are well liberated. The laboratory- and pilot-scale units were nearly able to produce the performance of the release analysis. An ash content reduction of about 40–45% was achieved while recovering 77% of the combustible material, which equates to an ash rejection of about 95%.

Mohanty and Honaker published a comparative evaluation of the three leading column flotation technologies. According to them, the packed column produced the best separation performance owing to its ability to support a deep froth zone. However, because of the absence of an air-sparging system and consequently larger bubbles, the solids-carrying capacity of the froth was minimal. On the other hand, the solids-carrying capacity or solids throughput achieved with the Jameson cell, was found to be maximal. The Microcell™ achieved maximum carrying capacity while providing a high energy recovery with a reasonably low amount of reagents. **Figure 7** shows the combustible recovery (amount of combustible material) as a function of product ash and total sulfur obtained for a coal using the three column technologies. The AFW (advanced flotation washability) is a limiting curve indicating the possible ash and sulfur that could be achieved using froth flotation technology. Note that the packed column provided both low ash and sulfur; however, the Microcell™ and Jameson cell both provided high combustible recovery.

In all work on coal flotation, a high ash rejection has been reported using column flotation technology. However, removal of pyritic sulfur has been marginal. The main reason for this is attributed to the ambivalent nature of coal pyrite; some pyrites are

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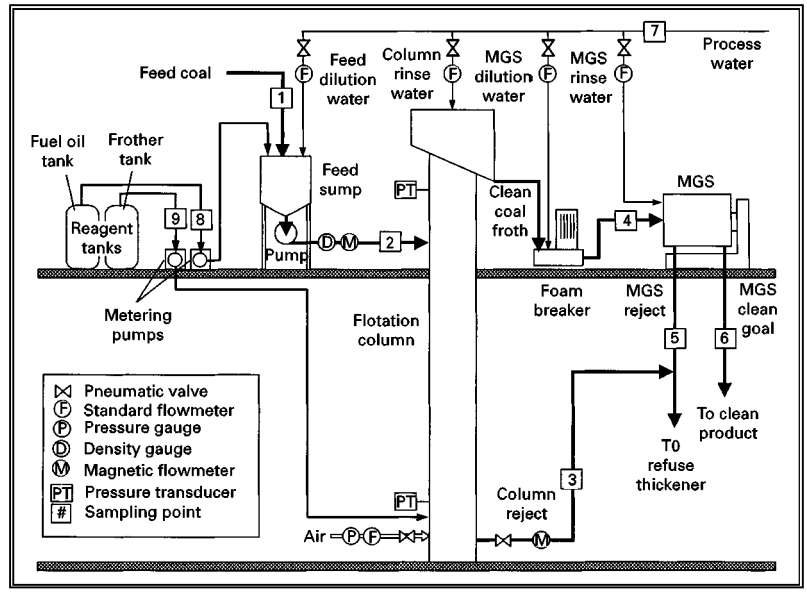

Figure 8 Schematic drawing of the combined advanced flotation/enhanced gravity separation circuit. (Luttrell *et al.* (1998), courtesy of Gordon and Breach Publishers.)

hydrophobic and some are hydrophilic in nature. In the case of coal, pyrite is always associated with some carbon which affords it hydrophobic and makes it float with coal. Luttrell *et al.* conducted studies on combining column flotation with an advanced gravity separation technology to remove pyrite from coal. The process flowsheet for the two-stage circuit is shown in **Figure 8**. A Microcell™ flotation column froth product after derating was sent to a multi-gravity separator (MGS) developed by the Mosley Ltd, UK. The MGS is similar to the shaking table, except that the particles in the flowing film are also subjected to centrifugal forces. **Figure 9** compares the performance of the flotation column alone to that obtained using the combined flotation column/MGS circuit. The rejection of pyritic sulfur improved from 60.5% to 83.6% and ash rejection improved from 83.8% to 87.7% using the combined techniques. Using the MGS unit, the loss of coal (energy) was very low, in the order of 2–3% points.

Coal flotation is a manually operated process. Recently, process optimization has been achieved through more efficient circuit designs and innovative sensor development. Some new approaches have been developed in the sensor area, which help in designing a controlled reagent delivery system. The Consol Co. has developed an inexpensive optical-based system shown in **Figure 10**. The main components of the detector are a glass tube, a photoconductor, an opaque barrier, and a light-emitting diode (LED). The light from the LED is reflected from the slurry to the main photoconductor. The photoconductor changes resistance in proportion to the light reflected from the tailing stream. The higher the tailings slurry ash content, the more light reflected back to the photoconductor and the lower the resistance.

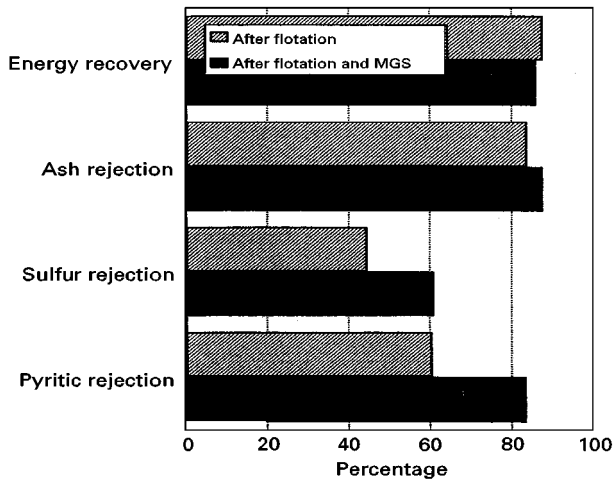

Figure 9 Separation performance obtained using the flotation column and combined flotation column/MGS circuit. (Luttrell *et al.* (1998), courtesy of Gordon and Breach Publishers.)

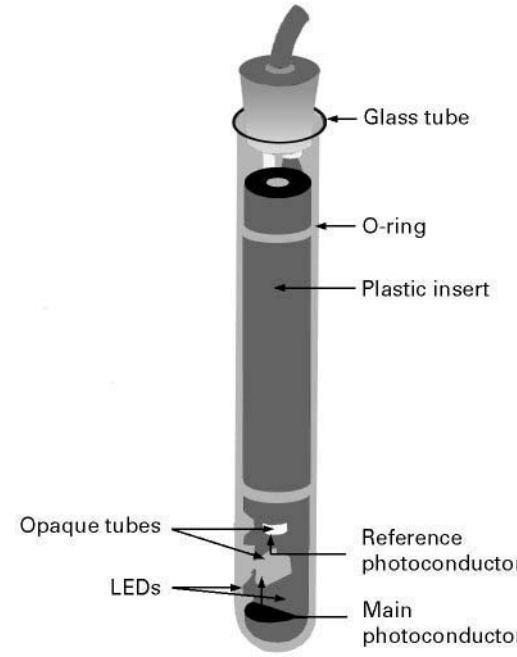

Figure 10 Optoelectronic tailings detector. (Meenan (1999), courtesy of SME, Littleton, Colorado, USA.)

A machine-vision or 'video-based' analyser system has also been successfully tested by Virginia Polytechnique Institute and State University. The video-based system could detect changes in slurries over an operating range of 60–90% ash.

Conclusion

In summary, coal flotation, column flotation has shown significant advantages from the technical and economic points of view. A combination of column with advanced gravity separators provides a much cleaner coal with low ash and pyritic sulfur contents. In the future, all new coal preparation plants will utilize column technology along with process optimization and sensors for the economic recovery of ultra-fine coal particles.

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COBALT ORES: FLOTATION

See **III / NICKEL AND COBALT ORES: FLOTATION**

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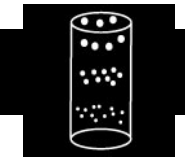
COLLOIDS: FIELD FLOW FRACTIONATION



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Introduction

When dealing with colloidal materials, the parameters of size and size distributions are needed, because many physicochemical processes, like aggregation and deposition on solid surfaces, are influenced by the size and size distributions of these materials.

For the analysis of submicron or supramicron colloidal particles, a sedimentation process, either under gravity or with centrifugal force, is necessary to sort different diameter particles into classes, and then to obtain an average size and a size distribution. Among the successful techniques used for this purpose, are electrophoretic mobility and the methods of size exclusion chromatography, hydrodynamic chromatography and field-flow fractionation (FFF).

FFF is a family of separation methods introduced by Giddings in 1966, but several groups all around the world have contributed significantly to the development. The various subtechniques of FFF are best suited to the separation and characterization of colloidal materials and macromolecules, including biological components ranging in size from proteins to living cells, environmental colloidal particles, as well as industrial polymers and colloids, powders, latexes and emulsions.

Principles of FFF

FFF is a flow elution method with retention achieved by using applied fields to drive the solutes into quiet flow regions. The applied fields are able to achieve